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# Mapping Landslides Susceptibility in a Traditional Northern Nigerian City

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Abstract*: As a result of dearth of relevant information about Landslides Susceptibility in Nigeria, the monitoring and assessment appears intractable. Hence, the study developed a Remote Sensing approach to mapping landslides susceptibility, landuse and landcover analysis in Jos South LGA, Plateau State, Nigeria. Field Observation, SPOT 5 2009 and 2012, ASTER DEM 2009, Geological Map 2006, Topographical Map 1966 were used to map Landslide Susceptibility and Landuse /Lancover Analysis in the study area. Geospatial Analytical Operations employed using ArcGIS 10.3 and Erdas Imagine 2014 include Spatial Modeling, Vectorization, Pre-lineament Extraction, Image Processing among others. Result showed that 72.38 % of the study area is underlain by granitic rocks. The landuse/cover types delineated for the study area include floodplain (29.27 %), farmland (23.96 %), sparsely vegetated land (15.43 %), built up area (13.65 %), vegetated outcrop (8.48 %), light vegetation (5.37 %), thick vegetation (2.39 %), water body (0.58 %), plantation (0.50 %) and mining pond (0.37 %). Landslide Susceptibility Analysis also revealed that 87 % of the study area is relatively at low to very low risk of landslide event. While only 13 % of the study area is at high to very high risk of landslide event. The study revealed that the susceptibility of landslide event is very low in the study area. However, possible landslide event in the hot spots could be pronounced and could destabilize the natural and man-made environmental systems of the study area.*

Keywords: *Landslides, Susceptibility, Geo-information, Jos South, Nigeria*

# 1. Introduction

Landslide is a geological phenomenon, which occurs as a result of ground movement. It can occur as rock falls, failure of unstable slopes, sand and debris flows on slopes (Irigaray, 2000). Landslide also known as slope movements occur when the down slope weight (driving force) exceeds the soil strength (resisting force) causing series of damages with direct and indirect consequences on human settlement and anthropogenic features. Landslides are very prominent where slope stability has been compromised and can be initiated by rainfall, erosion, volcanic activity, earthquakes, slope saturation of water, land use, land cover , slope terrain, change in groundwater, environmental disturbance and change of a slope by man-made construction activities, or any combination of these factors (Irigaray, *et. al*; 2007)

The landslide susceptibility maps delineate areas with different potentials for future landslide movement. The maps can be simple extrapolations of landslide-prone geologic units derived from geologic maps, or they can be complex computer-derived mathematical models involving nearly 100 factors that influence slope stability (Carrara, et al; 1995). Therefore, the magnitude of landslide could be assessed at micro scale, medium scale, and large scale levels respectively. Nowadays, different microwave interferometry and Geographic Information System (GIS) techniques are been used to monitor terrain changes between observations and to retrieve topographic maps from satellite imagery (Guzzetti *et al*., 1999, Irigaray, *et. al*; 2008).

Viewing the earth from space has become so important to understand the cumulative influence of human activities on our planet (Oluwafemi, 2010). Recently there had been numerous methods to analyze the susceptibility of slope movements by means of GIS (Carrara, et al; 1995) most of them based on the comparism between the determining factors and the territorial distribution of the movement observed (Lee *et al*.,2004). Over the years, environmental challenges such as extreme flooding, improper building patterns, poor drainage facilities, rock falls and landslide have serious detrimental effect on the built-up environment of Jos South and environs. Environmental indicators are showing that Jos South and its environs are gradually becoming vulnerable to slope failures, rock falls and landslide due to anthropogenic activities such as stone mining along roads and drainages, rock blasting among others. If these land uses and environmental hazards were not properly monitored and controlled may result into serious environmental hazards and social risks for the inhabitants in near future.

An overview of mapping landslide susceptibility in Jos South and environs is worthwhile however, much of the available information on landslide susceptibility focuses on the Eastern part of Nigeria. Hence, there is paucity of information on landslide susceptibility in North-Central, Nigeria. Apart from Ojigi□s work in 2012, in Gbagwalada Abuja, North Central, Nigeria, there is no empirical work with geospatial techniques in this part of the country. As a result of dearth of relevant information about landslide, rock falls and slope instability the monitoring and assessment appears intractable. The study attempted to use the Geographic Information Systems (GIS) and Remote Sensing to map landslide and rock fall susceptibility in the study area. This is with a view of aiding the policy makers in providing a framework for the effective control and monitoring of natural hazard.

# 2. Study Objectives

The specific objectives of the study are to:

i. create the digital elevation model of the study area;
ii. analyse landuse and landcover of the study are;
iii. identify landslide susceptibility and slope failure in the study area.

### *2.1 Study Area*

The Jos Plateau is located in the central part of Nigeria. The Jos South local government area, lies between latitudes 9° 30” to 9° 60” N and longitude 8° 40” E and 9° 00” (Figure 1). It is situated at the north western part of the state

with its headquarters at Bukuru, which is about 15 km from the state capital, Jos. The local government area has four districts: Du, Gyel, Kuru and Vwang districts. The local government area has total land area of about 1,037 km2 with a population of 306,716.

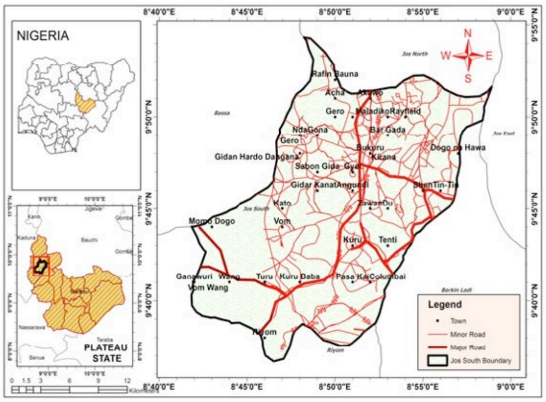


**Fig. 1.** Map of Nigeria showing the Study Area (Source: Oluwafemi 2010, 4)

### *2.1.2 Geology*

The Jos South is predominantly dominated by younger granite which was intruded through an area of older granite rock, making up the study area. These "younger" granites are thought to be about 160 million years old. This creates the unusual scenery of the Jos Plateau. Jos South local Government area has an average elevation of about 1,250 m above the sea leavel and stand at a height of about 600 m above the surrounding plains. The geology of the area comprises Precambrian basement complex rocks (migmatites, gneiss and older granites), the Jurassic younger granites (mostly biotites-granites) and the Tertiary as well as Quaternary volcanic rocks (mainly basalt, pumice, lava flows and ash deposits) (Olowolafe, 2004). The geomorphology is closely related to the underlying rock types. The area has been broadly divided into three broad physiographic units including (1) hills and mountains (2) dissected terrain (3) undulating landscapes. There are numerous hillocks with gentle slopes emerging from the ground like mushrooms scattered with huge boulders. The volcanic activity of about 50 million years ago created numerous volcanoes and vast basaltic plateaus.

### *2.1.3 Vegetation and Topography*

The Plateau lies within the northern Guinea Savanna vegetation zone, which is open woodland with tall grasses but has its own unique vegetation. There are numerous hillocks with gentle slopes emerging from the ground like mushrooms scattered with huge boulders (Olowolafe, 2004). Also volcanic activity 50 million years ago created numerous volcanoes and vast basaltic plateaus created from lava flows. This also produces regions of mainly narrow and deep valleys and pediment from the middle of rounded hills with sheer rock faces. The phases of volcanic activities involved in the formation of Plateau State have made it one of the mineral rich states in the country.

## 3. Materials and Method

This study adopted detailed GIS-based landslides susceptibility and landuse and landcover mapping as the basic methods using Remote Sensing data, Digital Elevation Model (DEM), and Geological Information as inputs. These data were manipulated, analysed and visualized in the ArcGIS environment.

### *3.1.1 Field Investigation*

The field investigation involved the identification of the anthropogenic activities that might trigger landslide within the study area. Likewise, various landuses and landcovers were identified and their location information was documented. The location data were used to aid the landuse/cover classification undertaken for the study area.

***3.1.2 Data Analysis and Presentation***

All analyses were conducted in GIS environment using the remotely sensed data as inputs. The first phased involved the modeling of the slope and landform layers for the study area, the generation of both plan curvature and profile curvature and the ultimate generation of the landslide susceptibility map. This set of geospatial analyses were conducted in ArcGIS 10.3 environment. The second phase involved the digital image analysis of the SPOT 5 imagery, which resulted to the generation of a landuse/cover layer. A supervised (pixel-based) image classification technique was adopted using Erdas Imagine 2014. This procedure resulted to the generation of many segments that were later regrouped into the identified landuse/cover classes within the study area during the field investigation. The third phase involved the superimposition of the lithological boundaries on the landslide susceptibility map in order to identify highly susceptible zones that would be impacted by catastrophes if they are exposed to indiscriminate anthropogenic activities such as mining (solid mineral exploitation and quarrying) and damming. Lastly, the susceptibility map was carefully analyzed in order to determine the vulnerability level of human life, socio-economic infrastructures and activities as well as the natural environment resources within the study area. The outcomes of the aforementioned analyses were presented in form of maps and tables. Figure 2 below shows the cartographic model adopted in the research.

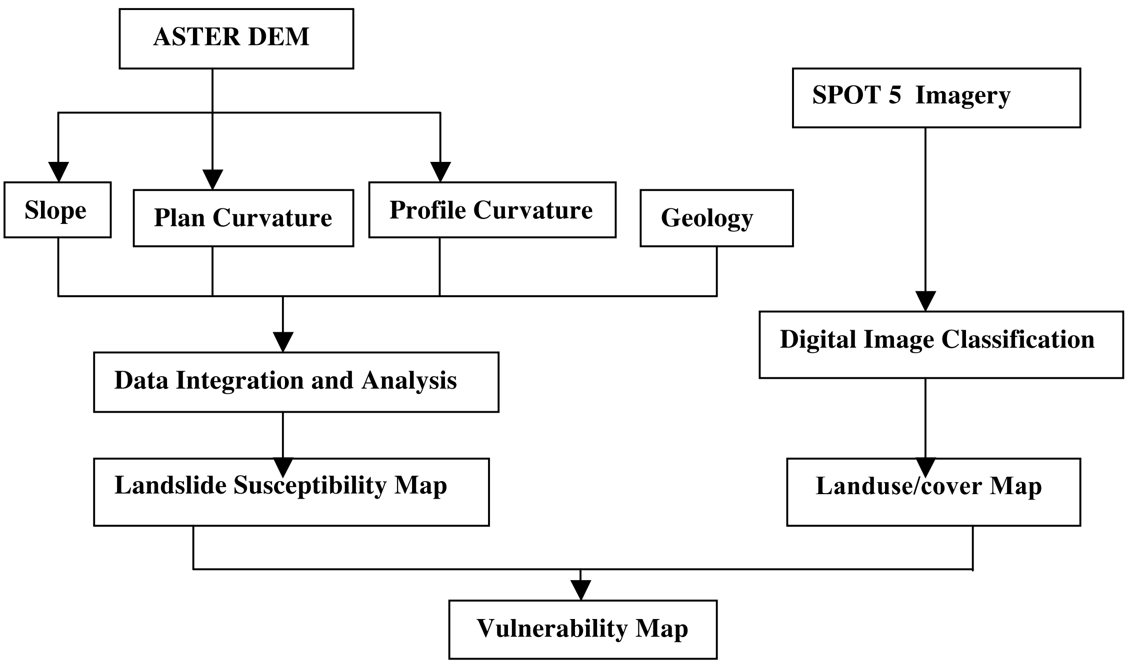


**Fig.2.** The Cartographic Model describing the GIS Analytical Procedure for Landslide Susceptibility Mapping (Source: Adapted from Oluwafemi 2010, 4)

# 4. Results

The result of the various analyses undertaken in the research was divided into two sections. The first section presents the analyses of the input layer and the output of the overall research activities. The second section presents the interpretation of the results and the susceptibility of the study area to landslide as well as the general vulnerability of the study area to landslide as a disaster.

## 4.1 Results

### 4.1.1 Terrain and Lithology

The terrain of the study area is characterized with high elevation ranging from 526 m.a.s.l. to 1603 m.a.s.l., which is a feature of plateau. The digital elevation model of the study area is presented in Figure 3. In-depth analysis of the terrain and its visual impression show that the terrain is relatively gentle with the intercalation of outcrops that rise abruptly above the surface, in places as well as the signature of fluvial processes such as river valleys, flood plains and deposition. Notable anthropogenic signature on the terrain of the study area includes the occurrence of mining induced ponds and mounds that are evident particularly in the southern axis of the study area.

The lithological map of the study area is presented in Figure 4. The lithology of the study area is characterized by Basement Complex rocks, which include granite (368.92 Km2), basalt (67.81 Km2), migmatite (38.88 Km2), biotite granite (19.98 Km2) and porphyritic biotite/biotite hornblende (14.11 Km2). The details of the statistics of the lithology are presented in Table 3. The analysis shows that 72.38 per cent of the study area is underlain by granitic rocks

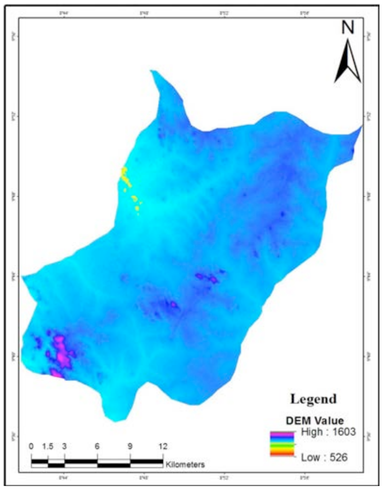


**Fig. 3.** Digital Elevation Model of the Study Area

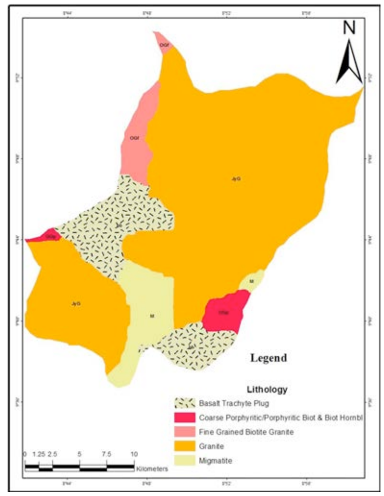


**Fig. 4**. Lithological Map of the Study Area

**Table 1**: Statistics of the Lithology of the Study Area

| S/No | Lithology | Area (Km$^2$) | % |
|---|---|---|---|
| 1 | Basalt Trachyte Plug | 67.81 | 13.30 |
| 2 | Fine Grained Biotite Granite | 19.98 | 3.92 |
| 3 | Coarse Porphyritic/ Porphyritic Biotite/ Biotite Hornblende | | |
| 4 | Migmatite | 38.88 | 7.63 |
| 5 | Granite | 368.92 | 72.38 |
| | | 509.70 | 100 |

Observation shows that lithological boundaries (which are indicators of geological structures such as joints, fractures and faults) occur within the study area. Although all the delineated rocks are relatively stable, failure could occur along lithological boundaries and steep terrain.

#### 4.1.2 Landuse/cover

The study area is characterized by both natural landcover and anthropogenic landuse, which have interwoven over time. The landuse/cover map of the study area is presented in Figure 5. The landuse/cover types delineated for the study area include floodplain (29.27 %), farmland (23.96 %), sparsely vegetated land (15.43 %), built up area (13.65 %), vegetated outcrop (8.48 %), light vegetation (5.37 %), thick vegetation (2.39 %), water body (0.58 %), plantation (0.50 %) and mining pond (0.37 %). The details of the landuse/cover statistics are presented in Table 4. 39.06 % of the study area is overlain by anthropogenic-induced landuses comprising settlements and infrastructures (such as road network), mining activities, agriculture and surface water impoundment. 29.27 % of the study area was delineated as floodplain that is usually subjected to sheet erosion during the raining season. This portion usually experience massive grassing activities particularly during the dry season. Although floodplain is categorized as natural landcover, larger part of this portion has been impacted by various anthropogenic activities that have left the area almost without vegetal cover. The obvious mining activities noticed across the study area shows that mining remains the major primary activities that dominate the economic activities within the study area. The impoundment of surface water in places across the study area indicates abundance of rainfall in the study area.

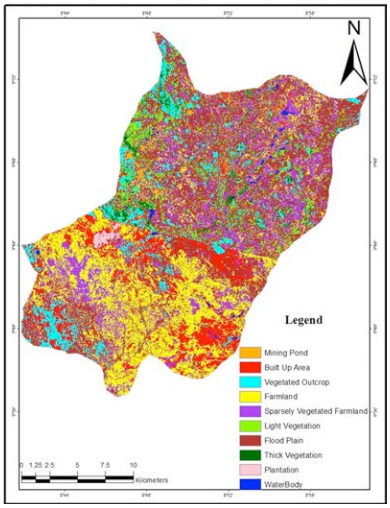


Fig.5. Landuse/cover Map of the Study Area

**Table 2**. Landuse/cover Statistics of the Study Area

| S/No | Landuse/cover | Area(Ha) | % |
|---|---|---|---|
| 1. | Mining Pond | 186.96 | 0.37 |
| 2. | Built Up Area | 6958.82 | 13.65 |
| 3. | Vegetated Outcrop | 4325 | 8.48 |
| 4. | Farmland | 12216 | 23.96 |
| 5. | Sparsely Vegetated Land | 7869.29 | 15.43 |
| 6. | Light Vegetation | 2737.63 | 5.37 |
| 7. | Floodplain | 14925.27 | 29.27 |
| 8. | Thick Vegetation | 1220.31 | 2.39 |
| 9. | Plantation | 253.85 | 0.50 |
| 10. | Waterbody | 299.69 | 0.58 |
| | | 50994.39 | 100 |

### 4.1.3 Landslide Susceptibility Analysis

The landslide susceptibility analysis involves two distinct GIS analyses. The first analysis involved the generation of the landslide susceptibility map by subjecting three derivative input layers (slope, plan curvature, profile curvature) into an advanced GIS analysis and modelling procedure. While the second analysis involved simple layer integration and overlay analysis of the susceptibility layer and lithological boundary layer in order to identify the locations where high to very high landslide susceptibility ratings coincide with lithological boundaries within the study area. The landslide susceptibility map of the study area is presented in Figure 6. Analysis shows that very low to low landslide susceptibility ratings were recorded for 87.22 per cent of the study area. While 9.21 per cent of the study area has moderate landslide susceptibility rating, only 3.57 per cent of the study area is of high to very high landslide susceptibility rating. Details of the statistics are presented in Table 3.

Figure 8 presents a map that displays the locations where areas of high landslide susceptibility rating coincide with lithological boundaries within the study area. This figure isolates three distinct critical locations where the chances of occurrence of incidence of landslide are very high. In these case, indiscriminate anthropogenic activities along or near the lithological boundaries especially in the locations where landslide susceptibility rating is high could aggravate the incidence of landslide within the study area. This could further be worsened by natural event such as torrential rainfall and flooding. This scenario is expected to be more pronounced in locations A and B (see Figure 7).

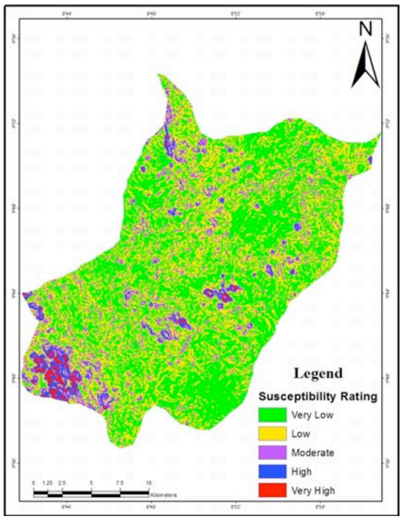


**Fig. 6.** Landslide Susceptibility Map of the Study Area

**Table 3**: The Statistics of the Susceptibility Map of the Study Area

| S/No | Value | Rating | Area(Ha) | % |
|---|---|---|---|---|
| 1 | 1 | Very Low | 25897.90 | 50.67 |
| 2 | 2 | Low | 18684.10 | 36.55 |
| 3 | 3 | Moderate | 4707.74 | 9.21 |
| 4 | 4 | High | 1344.41 | 2.63 |
| 5 | 5 | Very High | 480.62 | 0.94 |
| | | | 51114.77 | 100 |

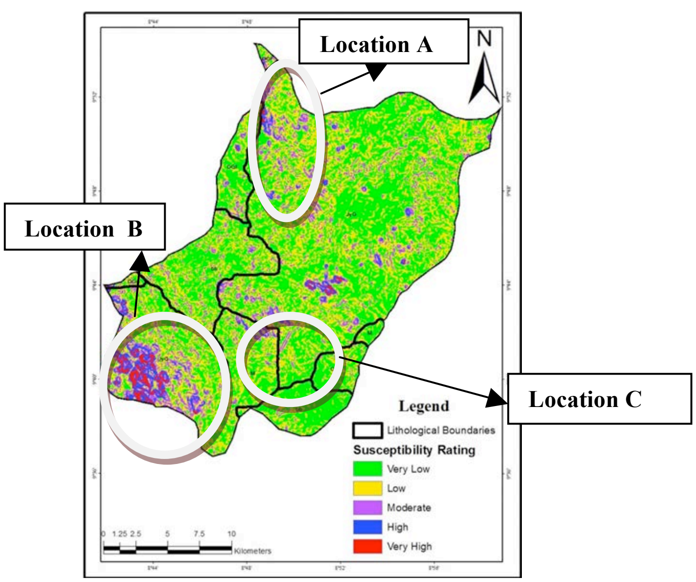


**Fig.7.** A Map showing Hot Spots of Landslide Susceptibility in the Study Area

Figure 8 present the landslide vulnerability map of the study area. Analysis showed that 13.65 per cent of the human settlements fall within and around the critical zones of landslide susceptibility within the study area. The high risk areas demarcated in Figure 8 shows the locations that will experience severe impact in the case of any landslide event within the study area.

## 5. Discussions and Recommendation

### 5.1.1 Potential Aggravating Factors of Landslide Event

The potential aggravating factors of landslide event identified within the study area include mining activities such as quarrying and solid mineral exploitation, deforestation and natural events such as heavy storm and the consequent flash flooding. The processes involved in quarrying have a great potential to trigger an extensive and catastrophic landslide event in the study area. The artificial procedure of rock fracturing (which involves the use of dynamite) could penetrate deeper and wider than expected. This in turn could lead to surface failure especially where there is increasing exerted pressure on the subsurface. The potential aggravating factor of landslide identified within the study area also includes solid mineral exploitation, which involves burrowing and creation of hallows of various sizes within the initially stable lithology. This assertion holds mainly for underground mining that usually leads to the removal of subsurface earth materials while the overlying layers are still intact.

Generally, the nature of unsustainable mining procedure in the study area indicates that the probability of occurrence of landslide event is very high. Another potential factor is the anthropogenic-induced deforestation across the study area. This is because; barren land and sparsely vegetated land are at higher risk of landslide compared to a densely vegetated land, which has more resilience due to the ability of the vegetation to regulate both surface and subsurface water flow. The major potential natural factor of landslide includes the heavy storm and its consequent flash flooding. The topographic characteristics of the study area usually induce heavy rainfall in contrast to the rainfall amount in the surrounding sub-regions. As a result, there is possibility that heavy storms could initiate flash flooding that could in turn lead to landslide especially within the delineated critical areas within the study area. Generally, potential factors of landslide events are mostly anthropogenic. However, natural factors such as heavy storm could trigger a catastrophic landslide event when other baseline conditions are in place.

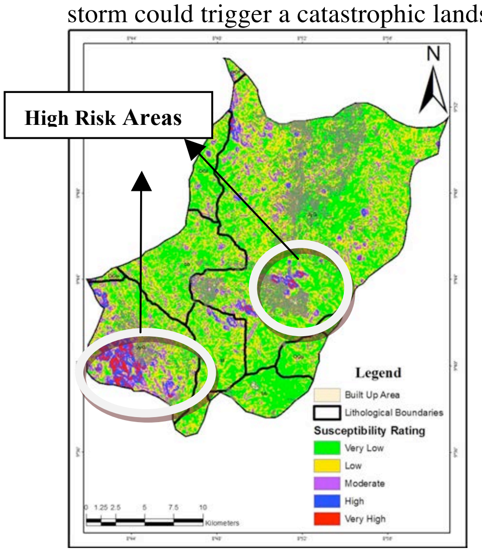


**Fig.8.** Landslide Vulnerability Risk of the Study Area

### 5.1.2 Landslide Susceptibility Analysis

According to the results of this study, 87 per cent of the study area is relatively at low to very low risk of landslide event. While only 13 per cent of the study area is at high to very high risk of landslide event. Base on this, it can be assumed that the susceptibility of landslide event is very low in the study area. However, possible landslide event in the hot spots could be pronounced and could destabilize the natural and man-made environmental systems of the study area.

### 5.1.3 Landslide Disaster Risk Analysis

Table 6 presents the vulnerable human settlements at different levels of potential destruction in the case of any extensive landslide disaster. Analysis showed that 13.65 per cent (1058.83 ha) of the built up area fall within zones that have high to very high landslide susceptibility rating. 17.20 per cent of this vulnerable human settlement lies within the very high landslide susceptible zone, while 23.20 per cent of the vulnerable built up area fall within 50 meter buffer zone around the very high susceptible area. 246.19 hectares (23.25%) of vulnerable human settlement lie within 100 meter buffer zone of the very high susceptible area, while 20.50 per cent and 15.85 per cent of the vulnerable human settlement lie within 150- and 200 meter around the very high susceptible zone respectively. The implication of this result is that at least 13.65 per cent of human settlement is highly vulnerable to landslide disaster within the study area. However, the extensive impact might be twice of this estimate. This is because; an event might trigger other unforeseen events that could be more severe and catastrophic than the index event.

**Table 4**. Vulnerable Human Settlements at different Levels of Potential Severity

| S/No | Severity Level | Area(Ha) | % |
|---|---|---|---|
| 1 | 1 | 182.14 | 17.20 |
| 2 | 2 | 245.61 | 23.20 |
| 3 | 3 | 246.19 | 23.25 |
| 4 | 4 | 217.11 | 20.50 |
| 5 | 5 | 167.78 | 15.85 |
| | | 1058.83 | 100 |

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